DYNAMICS OF SHORT SURFACE WAVES

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LONG-TERM GOAL

To improve our understanding of radar backscatter from the ocean surface at wavelengths less than or equal to 20 cm, and of related processes such as surface mixing and bubble formation.

SCIENTIFIC OBJECTIVES

To investigate the dynamics of breaking waves including micro-breakers, and the instabilities of fluid flows associated with spilling and plunging breakers; also the dynamics of parasitic capillary waves and of short gravity waves, and the role of bubbles in turbulent mixing.

APPROACH

A summary of recent research into the stability of steep gravity waves is to be found in the author's review (1). This includes also an account of the important effects of capillarity on short, steep gravity waves. Deep water capillary-gravity waves of solitary type were discovered theoretically (2), have been observed in wind-wave channels (3) and have been generated artificially in the laboratory, as described in last year's report. Although much is known about bubbles below 1m from the surface, comparatively little is understood about the top 50cm, and about the larger bubbles (radii > 0.3mm) which rise quickly to the surface. Yet these are intimately linked to turbulence from breaking waves. Many problems remain concerning these bubbles, particularly how to explain their formation and their anomalous rise velocities, which have a shallow minimum at radii between 0.3 and 6 mm.

WORK COMPLETED

Dynamical models are constructed on the basis of the Euler equations, when vicosity is negligible, or otherwise the Navier-Stokes equations. The author's preference is for simple analytical solutions rather than elaborate numerical schemes. Comparison with observation is emphasized. Where possible, experiments are conducted to verify theoretical results, and to obtain new information.

RESULTS

1. *Instabilities of surface shearing currents*:
   The simple shear-flow model of Stern and Adam (4) in which a shear layer of uniform depth and vorticity overlies an infinitely deep fluid, has been extended by the addition of an upper layer of uniform depth and constant velocity (5**)**. In this way it becomes possible to model the shearing currents that are observed on the forward face of spilling breakers. The normal-mode instabilities of such a model have been determined analytically and their properties calculated

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through the solution of a quartic polynomial equation. The dispersion relation has been determined and illustrated in its dependence on the Froude number $F=U/(gH)^{1/2}$, where H is the mean depth of the shear layer and U is the velocity difference; and on the ratio H_1/H_2, where H_1 and H_2 denote the mean depths of the surface layer and the base of the shear-layer. Two types of instability are found. Generally, if H_1/H_2 is moderate or small, the two types are distinct, but when $H_1/H_2 \geq 0.4924$ they may merge. The rates of growth of the fastest-growing modes, and their wavelengths, have been calculated; see Figure 1. These can be compared to the instabilities seen at the surface of breakers induced by a towed hydrofoil (see Figure 2). The wavelengths predicted by the model range from 13 to 22 cm.

It is expected that an extension of this investigation to three-dimensional instabilities will throw light on the observed generation of stream-wise vortices on the crests of waves with spilling breakers;

2. *Short surface waves:*
   The author's calculation of the viscous damping of steep capillary-gravity waves (7), has shown that capillary-gravity waves of solitary type have an unexpectedly large decay-rate — approximately twice that of wave trains of uniform amplitude. The theory has been found to agree with experiments of solitary waves by the author and Dr. Zhang (8). For a review paper on solitary capillary-gravity waves (9);

3. *Bubbles and turbulence near the ocean surface*:
   The author has embarked on laboratory experiments to determine the depth of penetration of bubbles below the surface in a plunging breaker, and to correlate these with a simple theoretical model of a turbulent jet. In these experiments a two-dimensional jet of known momentum and velocity is injected obliquely into the surface of a horizontal current. The larger bubbles entrained by the jet are observed photographically. Preliminary results were reported at a meeting of the Acoustical Society of America (10) in December 1996. Among the novel results was a measurable "jump," or change in surface level, between the upstream and downstream sides of the jet; and

4. *Three-dimensional flows*:
   As a preliminary to constructing models of three-dimensional, free-surface instabilities, the author has made a study of the relation between the vorticity and the curvature at a free surface (11). Although other authors have considered the same problem in special cases, the essential results have often been obscured by their generalised notation. In our work it is shown that for a three-dimensional flow, in addition to the expected component of vorticity *normal* to the flow and proportional to the curvature in the direction of flow, there exists also a component of vorticity *parallel* to the flow. This latter component vanishes only if the flow is in a principal direction, or if the point on the surface is an umbilic, where the principle curvatures are equal. Two proofs are given, one purely analytical and one partly geometrical. This result has led to a minor correction to a well-known text-book on fluid dynamics (12).

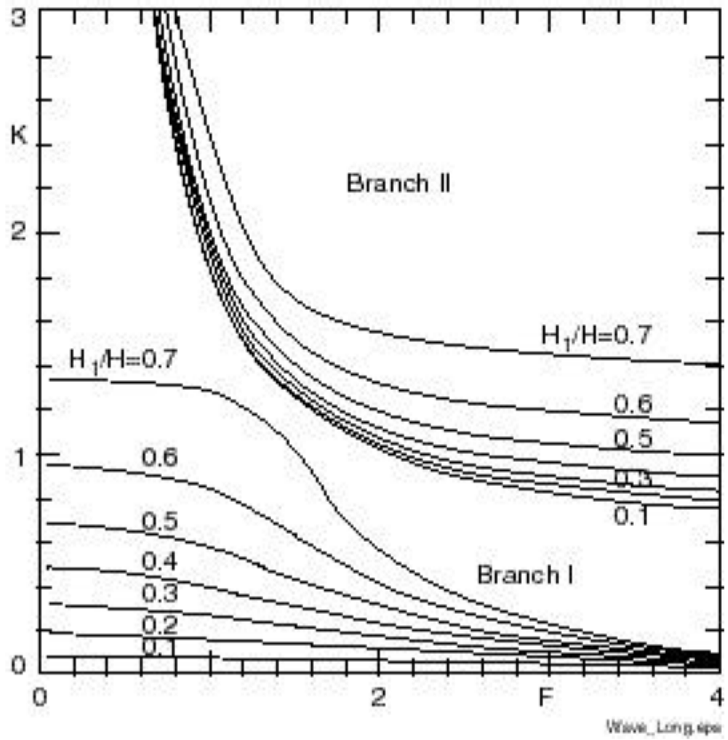

Figure 1. Wavenumbers =*kH* of the fastest-growing instabilities of a horizontal shearing flow, as a function of the Froude number $F=U/(gH)^{1/2}$ and the depth ratio H_1/H (5).

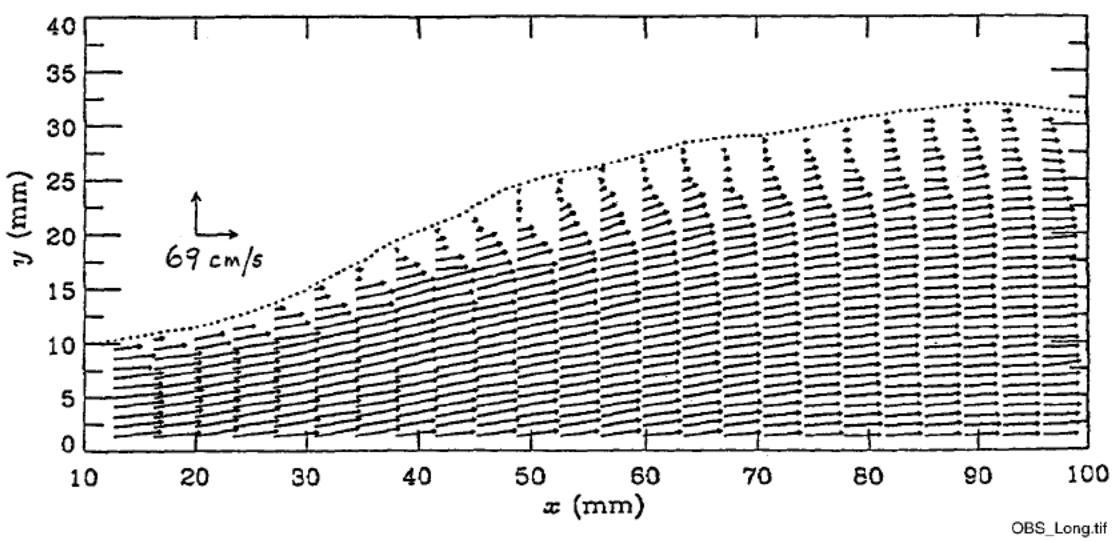

Figure 2. Observed velocity vectors and mean surface elevation relative to a 15cm hydrofoil towed to the left at a speed of 69 cm/s. Average of ten runs.

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PRESENTATIONS

1. Six lectures in S.I.O. Postgraduate Course 219: "Microstructure of the Sea Surface," Winter Quarter 1996.
2. "Shedding of vortex rings by collapsing cavities, with application to single-bubble sonoluminescence." Joint meeting of the A.S.A. and A.J.A., Honolulu, Hawaii, 4 Dec. 1996.
3. "Near-surface distribution of bubbles in the upper ocean." (Special Lecture). Joint meeting of the A.S.A. and A.J.A., Honolulu, Hawaii, 6 Dec. 1996.
4. "Solitons on deep water." Seminar, Physics Dept., Emory University, Atlanta, 14 Feb. 1997.
5. "The near-surface distribution of bubbles from a plunging breaker." ONR Workshop on the Dynamics of Bubbly Flows, U.C.S.D., La Jolla, 19 Feb. 97.
6. "Viscous dissipation in nonlinear surface waves." ONR Workshop on Free-Surface and Wall-Bounded Turbulence and Turbulent Flows," Calif. Inst. of Technology, Pasadena, 24 Feb. 1997.
7. "Solitary waves on deep water." Invited lecture, IMA Conf. on Wind-over-Wave Couplings: Perspectives and Prospects, Univ. of Salford, U.K., 9 Apr. 1997.
8. "Particle drift near an oscillating bubble." Symp. on Sonoluminescence, Univ. of Chicago, 12 Sep. 1997.
9. "Viscous streaming from an oscillating spherical bubble." Symp. on Sonoluminescence, Univ. of Chicago, 13 Sep. 1997.
10. "Solitons on deep water." Invited lecture, 26th Reunion of the Royal Spanish Physical Society, Las Palmas, Gran Canaria, 30 Sep. 1997.